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LUMINANCE THRESHOLDS DURING DARK ADAPTATION FOLLOWING PREADAPTATION TO CATHODE RAY TUBE DISPLAYS

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WRIGHT AIR DEVELOPMENT CENTER

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December 1952

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Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by Columbia University under USAF Contract No. AF 33(038)-22616 covering work on Visual Factors in Cathode Ray Tube Data Presentation. The contract was initiated under a project identified by Research and Development Order No. 694-45, "Presentation of Data on Radar Scopes," and was administered by the Psychology Branch of the Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, with Dr. Kenneth T. Brown acting as Project Engineer.

ABSTRACT

With the identification of the position of a luminous dial pointer as the threshold criterion, luminance thresholds were determined at various times during dark adaptation following preadaptation to Cathode Ray Tube displays. Each display consisted of a vertical trace line which traversed the Cathode Ray Tube screen at one of three rates. Dark adaptation curves, obtained after adaptation to the different displays are superimposed; initial thresholds are relatively low (-2.0 log millilamberts); and dark adaptation is essentially complete in five minutes. The findings are interpreted to indicate that in certain Air Force applications, viewing such displays causes a definite temporary loss in the observer's ability to read instrument dials and to perceive objects external to the aircraft.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Robert H. Blount

ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

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INTRODUCTION

In many Air Force situations an individual is required to perform visual tasks in dim illumination shortly after exposure to relatively high luminances. After the illumination to which an observer has been exposed is decreased or cut off, the eye gradually becomes more sensitive. Such an increase in sensitivity is called dark adaptation; its measurement is usually in terms of the minimum luminance required for light detection. Among the more important parameters which are known to influence the course of dark adaptation are the duration, luminance, and area of the preadaptation stimulation, and the duration, area, and spectral characteristics of the test stimulus (8, 12, 13, 15, 21, 22).

The present study of dark adaptation is dictated by a specific applied problem, viz., how does an observer's ability to read instrument dials vary with time in the dark after viewing a Cathode Ray Tube (CRT) display? More explicitly, during time in the dark after exposure to a CRT display, what minimum luminance of a dial pointer is required for correct identification of the position of the pointer?

The CRT displays consisted of vertical trace lines moving horizontally across the screen at three different rates. The dial employed to determine luminance thresholds was selected on the basis of recommendations by the Armed Forces-NRC Vision Committee (23).

APPARATUS

A schematic diagram of the optical system of the apparatus is shown in Figure 1. The apparatus is designed to provide the observer with (1) a CRT display as a preadapting source and (2) a dial face with luminous markers and a luminous pointer as the threshold test stimulus. The complete system, with the exception of the projection lamp and the surface of lens 1 facing the lamp, is enclosed in a wooden structure painted with flat black paint.

Preadaptation System

Light rays from a Cathode Ray Tube screen passed through the diaphragm of shutter 2, a manually operated studio shutter, and struck a mirror which reflected some of the rays, reducing the luminance by 53%. From the mirror, light rays passed through a 3 mm exit pupil to the eye. The CRT screen, subtending a visual angle of 10°12', was at an optical distance of 28 inches from the exit pupil.

The sweep circuit of an auxiliary cathode ray tube was electrically connected to the vertical deflection plates of the preadapting CRT, Type 304A, 5CP4A. The resulting display on the CRT screen was a vertical trace line. The width and luminance of the line were set to 1.5 mm and 160 millilamberts by means of the focus and intensity controls. The luminance at the exit pupil was 75 millilamberts. The width and luminance of the stationary vertical trace line on the CRT screen were measured by means of a technique originated and described by Ranken(19). The luminance value refers to the luminance at the center of the trace. Horizontal movement of the line across the screen was regulated by the sweep circuit. The three rates of movement used were one line crossing the CRT screen per second, 30 lines per second, and 60 lines per second. Two techniques were employed to measure the rates of horizontal movement of the vertical line. The one line per second rate was measured with a stop watch. The other two rates were determined by Lissajous patterns obtained with the aid of a photosensitive tube used in conjunction with an amplification system.

The CRT was "warmed up" at least five minutes before being exposed to the observer. Both tubes were operated at a monitored 115 volts AC.

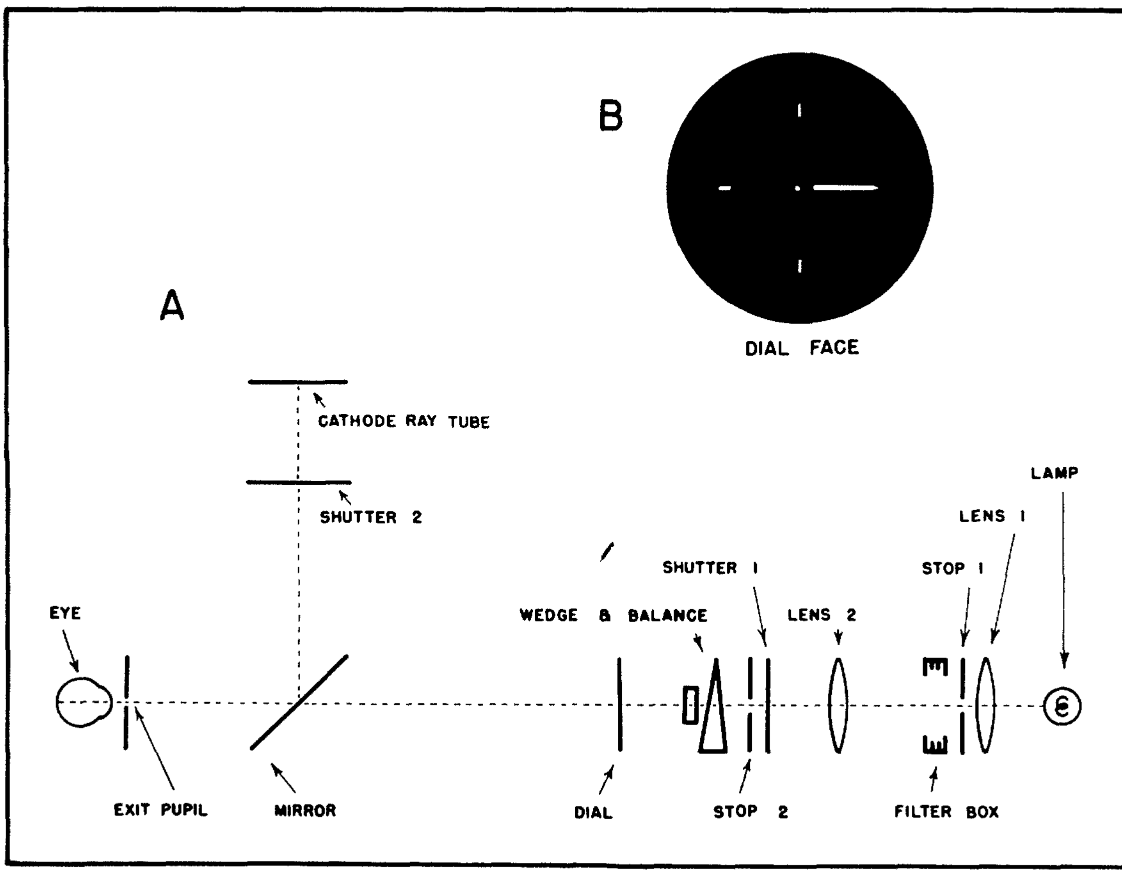

Figure 1. Schematic diagram of the optical system of the apparatus. See text for full explanation.

Threshold Determination System

A seasoned 75-watt projection lamp was located at focal distance from lens 1 and operated at a monitored 120 volts DC. This lamp served as the source for threshold determinations. Parallel rays passed from lens 1 to lens 2 which focused them at shutter 1, a sector-disk shutter with an exposure duration of 0.019 second, driven by a synchronous motor at 60 rpm. When shutter 1 was activated by means of a solenoid circuit, a circular patch of light was cast on the back surface of the dial which was located 28 in. from the exit pupil.

The flat black metal dial face was fitted with four flashed opal radial markers, 90° apart. The inner tip of the largest marker, the pointer, was 31' visual angle distant from the dial center; the pointer dimensions were $2^{\circ}18'$ by 12'. The inner tip of each of the other markers was $2^{\circ}26'$ visual angle from the dial center; each measured 4' by 27'. Since the completely rod-free area of the retina extends 50' laterally from the foveal center (Polyak, 18), 19' of the pointer fell in a rod-free area. Therefore at luminances below cone threshold only $1^{\circ}59'$ (or less) of the pointer's length effectively stimulated the observer. Rotation of the dial was accomplished by a cable control system. Four pointer positions were used: up, down, left, and right. The last position is shown in Figure 1B. The red tip (12' visual angle) of a curved lucite rod, located at the center of the dial face, served as the fixation point; it was illuminated with a 6 volt screened source.

The light rays which passed through the dial markers struck the mirror, which transmitted some of the light, reducing the luminance to 8% of its full value. From the mirror the light rays passed through the exit pupil to the eye. Circular stop 1, 3.7 cm in diamter, was flush with the central portion of lens 1; it served to limit the diameter of the light beam. Stop 2, which measured 10 mm vertically by 3.2 mm horizontally, was contiguous with shutter 1; it excluded stray light and aided in the rapid onset and termination of the flash on the dial back. Luminance was controlled by a fixed filter and by the wedge and balance.

The pointer luminance was determined by replacing the dial with a flashed opal plate of the same type used to construct the markers. The mirror, the exit pupil section, and the filters were removed, shutter 1 was opened, and the wedge was set to allow maximum transmission. Luminance measurements were then made with a Macbeth illuminometer.

The density of the filter was measured with a Marten's photometer, and the wedge scale values were checked with an Eastman densitometer. The mirror's transmission and reflectance were determined with a Macbeth illuminometer. Beckman spectrophotometer measurements indicated that the mirror transmitted a slightly greater percentage of the light of longer wavelengths.

PROCEDURE

Two experienced observers participated in the experiment; observer MK, a female, was slightly hypermetropic; observer RH, a male, slightly myopic. Both observers possessed normal color vision. The right eye of each subject was used for light adaptation and for threshold determinations.

The general procedure was the same during all experimental conditions. An observer was first dark adapted for 5 minutes, then light adapted for five minutes with the CRT screen as the light source, and finally presented with test flashes to determine thresholds at intervals during the subsequent 30 minutes. The only variation from one condition to another was in the characteristics of the light-adaptation stimulus. The vertical trace line moved across the CRT screen at rates of 1, 30, and 60 times per second. Details of the procedure follow.

The observer entered a light tight cubicle and the dark adaptation period began. At 15 seconds, 5 seconds, and 1 second before the end of this period the observer was given auditory warning signals to position his chin in the chin rest and to regard the fixation point. At the end of the dark-adaptation period the experimenter opened shutter 2, thereby exposing the CRT screen and initiating the light adaptation period. Warning signals were given 15 seconds, 5 seconds, and 1 second before termination of the light adaptation period; at the completion of the period the experimenter closed shutter 2 and turned off the CRT.

At predetermined intervals during the next 30 minutes test flashes were presented to determine thresholds. Preceding each flash, 15, 5, and 1 second warning signals were given to allow the observer to position his chin and fixate the red point. At the proper time the experimenter momentarily closed the solenoid circuit and thus allowed shutter 1 to complete one rotation. The observer then stated the position of the pointer if it was seen, or answered "no" if it was not seen; the experimenter recorded the observer's response and the pointer's position. Before the next test flash, the experimenter adjusted the wedge setting and the position of the pointer. The observer maintained the luminance of the fixation point at a near threshold level by means of a potentiometer control in the darkroom.

The opening of the sector disk shutter rotated through 270° before encountering the optical axis of the test source, so the flash appeared 0.75 seconds after the solenoid circuit was closed. The solenoid circuit was momentarily closed at the 30th second after the end of light adaptation and at 30 second intervals thereafter during the first 5 minutes, at every minute for the next 5 minutes, and at every other minute during the subsequent 20 minutes. In addition, in one set of experimental sessions under each condition, the solenoid circuit was momentarily closed 5 seconds after the end of light adaptation; in another set it was closed at the moment when shutter 2 was closed, thereby presenting a test flash 0.75 second after the termination of light adaptation. The latter was accomplished by means of a detachable contact attached to the extension arm of shutter 2.

During the first session under each of the conditions of light adaptation the experimenter endeavored, by judiciously adjusting the wedge setting, to obtain a frequent alternation of correct identifications and of negative responses. In subsequent sessions the experimenter adjusted the wedge in an attempt to obtain both a correct identification and a negative judgment at each of the times when the test flashes were presented. If a difference of 0.2 log units or less existed between the highest luminance at which a negative response was made and the lowest luminance at which a correct identification occurred, the midpoint between the two luminance values was taken as the threshold point. Mistakes in identification of the pointer's position were treated as negative responses. Four 30 minute testing sessions were usually required to obtain a sufficient number of experimental points under each condition of light adaptation; four shorter testing sessions were necessary to obtain the initial experimental point under each condition.

Check experiments indicated no appreciable differences in the dark adaptation function when either the duration of the initial dark adaptation period was increased or the interval between test flashes was increased.

RESULTS AND DISCUSSION

Figure 2 presents log threshold luminance values as a function of time in the dark following three conditions of light adaptation to a CRT screen. Only the initial ten minutes of the course of dark adaptation are shown. The drop in threshold during the subsequent twenty minutes was gradual and of small magnitude; after thirty minutes in the dark the threshold was between 0.2 and 0.3 log units lower than the threshold at ten minutes.

Four findings are evident from a study of Figure 2. First, the dark adaptation function is the same following each condition of light adaptation. For different conditions the differences between the thresholds at any given time are well within the range of variability ordinarily obtained in dark adaptation studies. Secondly, the initial threshold points, obtained 0.75 seconds after the completion of light adaptation, are relatively low. For observer MK the three initial threshold values are -2.12, -2.02, and -2.02 log millilamberts, respectively, for the 1, 30, and 60 lines/sec conditions of light adaptation; for RH the corresponding threshold values are -1.98, -1.93, and -1.70 log millilamberts. A third point to be noted is the amount of decrease in threshold as a function of time. If we consider the extreme experimental points, Figure 2 shows that the threshold of MK drops approximately

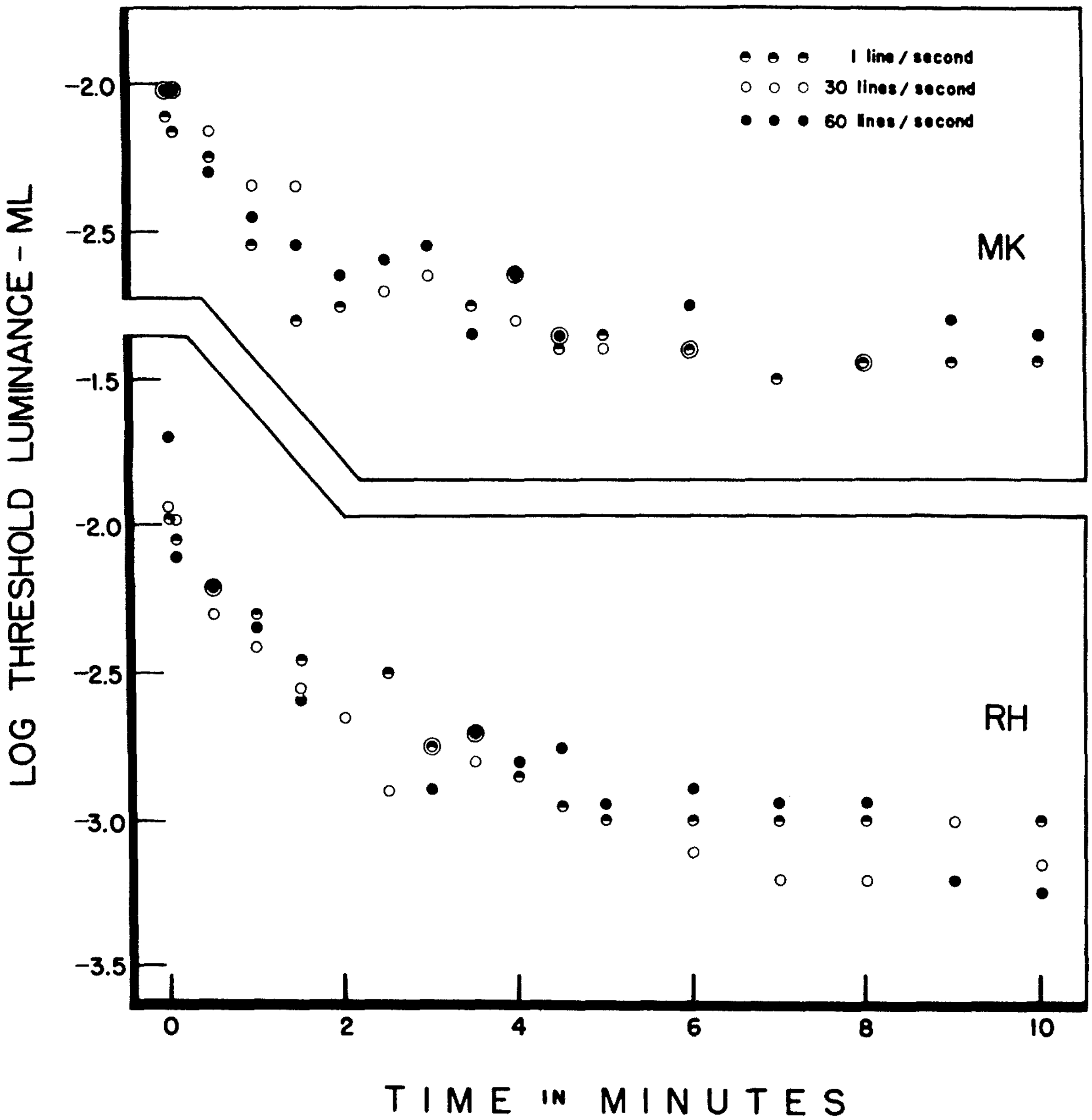

Figure 2. Log threshold luminance as a function of time in the dark following preadaptation to CRT displays. The rate at which the vertical trace line scanned the CRT screen is indicated by the coding of the datum points.

one log unit, while that of RH drops about one-and-one-half log units. The greater threshold change of RH is due partly to the relatively high initial threshold of RH following the 60 lines/sec condition of light adaptation. The fourth finding is that most of the drop in threshold occurs during the first five or six minutes; i.e., dark adaptation is essentially complete in about five minutes. These findings are in accord with the data of previous dark adaptation studies (2, 12, 15, 21).

Before discussing the application of these results to Air Force problems it is important to consider the differences which exist between the task of the observer in the experimental situation and the task of the pilot in the practical one. The present study obtained thresholds corresponding to approximately 50% correct responses. A criterion of 100% correct response, as is desired in flying, would raise the threshold values to the order of one-half log unit above those of the present experiment (14). Secondly, the experimental task involves a low level of visual acuity. A dark adaptation curve based on a criterion of somewhat higher acuity would be of the same form as that of the present experiment but would be displaced upward on the ordinate (1, 20). If a very high level of acuity is required (as, for example, in distinguishing fine gradation markers on a dial face), the effect on the dark adaptation curve would be to reduce the range of threshold luminances and the time required to reach minimum threshold. The use of transmitted light in this experiment rather than reflected light is a third point of difference between the experimental situation and certain practical situations. With reflected light, contrast is decreased and consequently the pointer luminance threshold will be raised (6). In short, in situations involving decreased contrast, higher visual acuity, or 100% correct response, threshold luminances will be higher than those obtained in the present experiment.

The duration of exposure of the dial face is another point of difference between the experimental and the actual situation. In practice the time a pilot fixates an instrument dial is of the order of one or two seconds (3, 4, 10, 11); in the present experiment the duration of exposure was 0.019 second. Below a certain "critical duration" the eye is capable of integrating the effects of light energy distributed over an interval of time (7, 8, 9, 16); i.e., when the duration of exposure is increased the luminance required for threshold decreases. A consideration of the data of Graham and Margaria (8) indicates that if the duration of exposure in the present experiment were increased to 0.10 second or longer the luminance thresholds would probably be decreased a few tenths of a log unit.

One other factor to consider is the magnitude of the preadapting luminance of the CRT screen. However, the method of measuring CRT screen luminance recently developed by Ranken (19), has not yet been applied to the calibration of the luminance of operational radar screens.

A direct comparison of the luminance value used in this experiment, and luminances commonly employed in actual operations is therefore not possible at present.

It is probable that the cumulative effect of all the above mentioned factors would be to make the threshold values in many applied situations higher than those obtained in the present experiment. The amount by which the thresholds would be raised would, of course, depend upon the specific situation.

Keeping in mind the conclusion that the thresholds obtained in this experiment may be lower than those in most Air Force situations, we may next consider the application of the experimental results to Air Force problems. Three questions may profitably be considered: a) How does viewing CRT displays affect subsequent reading of intruments? b) How does it affect one's ability to perceive objects outside the aircraft? c) After viewing CRT displays, how much time must pass before the eye once again becomes completely dark adapted?

A study of Cole, McIntosh and Grether (5) provides information relevant to the first question. They found that the average minimum luminance of the red flood lighting system required for safe flight is approximately 0.003 millilambert. Brown and Grether (2) determined that the red floodlight luminance of 0.003 millilambert is equivalent (in terms of equal visual acuity) to a low color temperature white light of approximately 0.016 millilambert. The initial threshold of the present experiment is about 0.01 millilambert, just below the minimum equivalent low color temperature white light required for safe flight. Therefore, when the factors of 100% correct response, lower contrast, etc., are considered, the results of this experiment suggest that under some flying conditions viewing CRT displays may cause a definite loss in instrument visibility.

Any loss in visual sensitivity which results from viewing CRT displays is, of course, not restricted to instrument visibility; there is a general loss in visual sensitivity. Therefore, under flying conditions which require high sensitivity to objects outside the aircraft preadaptation to CRT displays may have definite detrimental effects.

The data of Figure 2 indicate that, following preadaptation to the CRT display, the eye must remain in the dark for 5 or 6 minutes before maximum visual sensitivity is regained. From this we may infer that land marks on the ground and aerial objects of very low luminance may not be detected by aircraft personnel until 5 minutes have passed since exposure to the CRT display.

The CRT displays stimulate any given retinal point intermittently. When the rate at which the trace line crosses the screen is increased, the duration of each stimulation of a given retinal point is decreased and there is a compensatory increase in the frequency of stimulation. Therefore, the total time of stimulation for any retinal point (i.e., duration of each stimulation times the number of stimulations) is the same under all three conditions of light adaptation.

A dark adaptation experiment by Mote, Riopelle and Meyer (17) is comparable to the present study in that an intermittent light source was used for preadaptation. In both experiments the product of duration times frequency of stimulation equalled a constant. Though a great many differences exist between the two experiments, including the size of the retinal area stimulated, the retinal location of the test stimulus, and the light-dark ratio, a few general comparisons may be made. First, in both experiments the dark adaptation curves obtained after various conditions of intermittent stimulation to a given luminance were the same. Secondly, in the conditions of Mote <u>et al</u> most comparable to those of the present study, the curves show a drop of about 1.5 to 2.2 log units and dark adaptation is essentially complete in about five minutes. Thus it may be concluded that the scan rate of a CRT display has little if any effect on the subsequent dark adaptation curve.

The displays used in the present experiment were quite similar to the presentation of a B-scan radar scope. However, in generalizing our results to actual radar displays the reader should note that B-scope phosphors are of relatively long persistence, whereas the phosphor used in the present experiment (P-4) was of relatively short persistence.

SUMMARY AND CONCLUSIONS

Luminance thresholds were determined after various durations of dark adaptation following preadaptation to CRT displays. The displays consisted of a vertical trace line moving horizontally across the screen at three different rates. The threshold criterion was the identification of the position of a luminous dial pointer.

1. Dark adaptation curves following the three conditions of preadaptation are superimposed. Thus the scan rate of a CRT display has little or no effect on the subsequent dark adaptation curve.

2. Initial thresholds (0.75 second after the end of preadaptation) have a value of approximately -2.0 log millilamberts.

3. The threshold drops one to one-and-one-half log units before reaching a limiting value; this drop occurs during the first five minutes of dark adaptation.

4. Viewing CRT displays has a temporary detrimental effect upon the visual efficiency of aircraft personnel:

   a. Ability to read instrument dials is impaired.
   b. Visual sensitivity to objects external to the aircraft is lowered.

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